WRITTEN STATEMENT BY
DR. THOMAS R. KARL
DIRECTOR, NATIONAL CLIMATIC DATA CENTER
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA)
U.S. DEPARTMENT OF COMMERCE

FOR AN OVERSIGHT HEARING:
INTRODUCTION TO CLIMATE CHANGE

BEFORE THE
COMMITTEE ON GOVERNMENT REFORM
U.S. HOUSE OF REPRESENTATIVES

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Mr. Chairman and Members of the Committee: As Director of the National Climatic Data Center, which is part of the National Environmental Satellite, Data, and Information Service (NESDIS) within the National Oceanic and Atmospheric Administration (NOAA), and as Program Manger for one of five different NOAA Climate Goal Programs (Climate Observations and Analysis), I am pleased to have the opportunity to testify before you today. The National Climatic Data Center is the world's largest archive of weather and climate data, which includes data critical to understanding climate variability and change, and also acts as the Nation's Scorekeeper regarding the trends and anomalies of weather and climate.

The U.S. Climate Change Science Program (CCSP) integrates federal research on global climate change, as sponsored by thirteen federal agencies.[1] CCSP is a multi-agency program charged with: investigating natural and human-induced changes in the Earth's global environmental system; monitoring, understanding, and predicting global change; and providing a sound scientific basis for national and international decision-making. The CCSP combines the near-term focus of the Administration's Climate Change Research Initiative — including a focus on advancing the understanding of aerosols and carbon sources and sinks and improvements in climate modeling — with the breadth of the long-term research elements of the US Global Change Research Program.

Since CCSP was created in 2002, the program has successfully integrated a wide range of research, climate science priorities and budgets of the thirteen CCSP agencies. CCSP integrates research and observational approaches across disciplinary boundaries and is also working to create more seamless approaches between theory, modeling,

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[1] The CCSP participating agencies include the Departments of Agriculture, Commerce, Defense, Energy, Health and Human Services, the Interior, State, and Transportation, the National Science Foundation, the Environmental Protection Agency (EPA), the National Aeronautics and Space Administration (NASA), U.S. Agency for International Development, and the Smithsonian Institution. Additional CCSP liaisons reside in the Office of Science and Technology Policy, the Council on Environmental Quality, the National Economic Council and the Office of Management and Budget.

observations, and applications required to address the multiple scientific challenges posed by changes in climate. With an approximately $2 billion annual expenditure in 2006, CCSP is taking on the most challenging questions in climate science and is developing products to convey the most advanced state of knowledge to be used by federal, state and local decision makers, resource managers, the science community, the media, and the general public. Over the next two years CCSP will be completing a series of 21 Synthesis and Assessment Reports, the first of which was just released a few months ago. The collection of these Synthesis and Assessment Report will address many of the issues pertinent to this testimony.

I will provide an overview of the current understanding of the atmosphere in terms of: the role that greenhouse gases play in the atmosphere; evidence for how greenhouse gases are already influencing the climate in both general and in specific ways; an introduction to the use of global climate models, and some of the evidence that has led a number of assessments, including the IPCC (2001), the National Research Council (2002), and the Climate Change Science Program Synthesis and Assessment Report 1.1 (Karl et al., 2006) to link the rise in temperature over the past several decades to increases in greenhouse gases and related changes climate.

Atmospheric Composition and Greenhouse Gases

The natural "greenhouse" effect is real, and is an essential component of the planet's climate process. A small percentage (roughly 2 percent) of the atmosphere is, and long has been, composed of greenhouse gases (water vapor, carbon dioxide, ozone and methane). These gases effectively prevent part of the heat radiated by the Earth's surface from otherwise escaping to space. The response of the global system to this trapped heat is a climate that is warmer than it would be otherwise without the presence of these gases. In the absence of these greenhouse gases the temperature on Earth would be too cold to support life as we know it today. Of all the greenhouse gases, water vapor is by far the most dominant, but other gases are more effective at trapping heat energy from certain portions of the electromagnetic spectrum whereas water vapor is semi-transparent to heat escaping from the Earth’s surface.

In addition to the natural greenhouse effect outlined above, there is a change underway in the greenhouse radiation balance. Some greenhouse gases are increasing in the atmosphere because of human activities and increasingly trapping more heat. Direct atmospheric measurements made over the past 50 years have documented the steady growth in the atmospheric abundance of carbon dioxide. In addition to these direct real-time measurements, ice cores have revealed the atmospheric carbon dioxide concentrations of the distant past. Measurements using air bubbles trapped within layers of accumulating snow show that atmospheric carbon dioxide has increased by nearly 35 percent over the Industrial Era (since 1750), compared to the relatively constant abundance of carbon dioxide over at least the preceding 750 years of the past millennium (Figure 1). The predominant cause of this increase in carbon dioxide is the combustion of fossil fuels and the burning of forests. Further, methane abundance has doubled over the Industrial Era, but the increase of methane has slowed over the recent decade for reasons not clearly understood. Other heat-trapping gases are also increasing as a result of human activities. We are unable to state with certainty the exact rate at which these gases will continue to increase because of uncertainties in future emissions, as well as uncertainties regarding how these emissions will be taken up by the atmosphere, land, and oceans. We are certain, however, that once in the atmosphere these greenhouse gases have a relatively long residence time, on the order of decades to centuries (IPCC, 2001). This means they become well mixed throughout the globe.

Increases in heat-trapping greenhouse gases are projected to be amplified by feedback effects, such as changes in water vapor, snow cover, and sea ice. As atmospheric concentrations of carbon dioxide and other greenhouse gases increase, the resulting increase in surface temperature leads to less sea ice and snow cover helping to raise temperatures even further. As snow cover and sea ice decrease, more of the Sun's energy is absorbed by the planet, instead of being reflected back to space by the snow cover and sea ice. Present evidence also suggests that as greenhouse gases lead to temperature increases, evaporation increases leading to more atmospheric water vapor (Trenberth, et al., 2005; Soden, B.J., et al., 2005). Additional water vapor (which, as mentioned above, is the dominant greenhouse gas) acts as a very important feedback to further increase temperature. The most uncertain feedback is related to clouds. Specifically, changes in cloud frequency, location, and height. The range of uncertainty spans from a significant positive feedback to no feedback, or even a slight negative feedback. Our present understanding suggests that these feedback effects account for at least half of the warming (IPCC, 2001; Karl and Trenberth, 2003). The exact magnitude of these feedback effects remains a significant source of uncertainty related to our understanding of the impact of increasing greenhouse gases. For example, increases in evaporation and water vapor affect global climate in other ways besides increasing temperature such as increasing rainfall and snowfall rates, and accelerating drying during droughts. The increase in greenhouse gas concentrations in the atmosphere implies a positive radiative forcing, i.e., a tendency to warm the climate system.

Particles (or aerosols) in the atmosphere resulting from human activities can also affect climate. Aerosols vary considerably by region. Some aerosol types act in a sense opposite to the greenhouse gases by reflecting more solar radiation back to space than the heat they absorb, and cause a negative forcing or cooling of the climate system (e.g., sulfate aerosol). Other aerosols act in the same way as greenhouse gases, and warm the climate (e.g., soot). In contrast to the long-lived nature of carbon dioxide (centuries), aerosols are short-lived and removed from the lower atmosphere within a few days. Therefore, human-generated aerosols exert a long-term forcing on climate only because their emissions continue each day of the year. Aerosol effects on climate can be manifested directly by their ability to reflect and trap heat, but they can also have an indirect effect by changing the lifetime of clouds and changing the clouds reflectivity to sunshine. The magnitude of the negative forcing of the indirect effect of aerosols is highly uncertain, but may be larger than negative forcing of the direct effect of aerosols (IPCC, 2001).

Emissions of greenhouse gases and aerosols continue to alter the atmosphere in ways that are expected to affect the climate, e.g., temperature and precipitation extremes, reduction in snow cover and sea ice, changes in storm track and intensity (IPCC, 2001). By altering the planet's natural energy flows changes in temperature, evaporation, precipitation, storms are affected. There are also natural factors which exert a forcing on climate, e.g., changes in the Sun's energy output and short-lived (a few years) aerosols in the stratosphere following episodic and explosive volcanic eruptions. If we sum up all the possible influences of natural and human climate forcings over the past several decades then the increase of greenhouse gases are larger than all the other forcings and continue to grow disproportionately larger (Karl and Trenberth, 2003; IPCC, 2001).

Human activities also have a large-scale impact on the land surface. Changes in land use through urbanization and agricultural practices, although not global, are often most pronounced where people live, work, and grow food, and are part of the human impact on climate. Large-scale deforestation and desertification in Amazonia and the Sahel, respectively, are two instances where evidence suggests there is likely to be human influence on regional climate (Andreae et al., 2004; Chagnon and Bras, 2005). In general, city climates differ from those in surrounding rural green areas, because of the "concrete jungle" and its effects on heat retention, runoff, and pollution, resulting in urban heat islands.[2] (Bornstein and Lin, 2000; Changnon et al., 1981; Landsberg, 1983; Karl et al., 1988; Peterson, T.C., 2003; Karl et al., 1988; Jones et al., 1990).

There is no doubt that the composition of the atmosphere is affected by human activities. Today greenhouse gases are the largest human influence on atmospheric composition.

What exactly is a climate model and why is it useful?

Many of the scientific laws governing climate change and the processes involved can be quantified and linked by mathematical equations. Figure 2 shows schematically the kinds of processes that can be included in climate models. Among these are many earth system components such as atmospheric chemistry, ocean circulation, sea-ice, land-surface hydrology, biogeochemistry[3], atmospheric circulation, etc. The physics of many, though not all, of the processes governing climate change are well understood, and may be described by mathematical equations. Linking these equations creates mathematical models of climate that may be run on computers or super-computers. Coupled climate models can include mathematical equations describing physical, chemical, and biogeochemical processes, and are used because the climate system is composed of different interacting components.

In fact, coupled climate models are the preferred way to approach climate modeling. This is because if we put all our understanding into a single model, it would be too complex to run on any existing computer systems. The decisions for how to build any given climate model includes trade-offs between the complexity of the model and number of Earth system components

[2] The global impact of these urban heat islands has been extensively analyzed and assessed to ensure measurements of global temperature are not biased by local urban heat islands.
[3] Biogeochemistry refers to the biological-chemistry of the Earth system, such as the uptake of atmospheric carbon by land and ocean vegetation.

included, the horizontal and spatial resolution within the model, and the number of years of simulations the model can produce per day of computer time. Consequently, there is a hierarchy of model complexity, often based on the degree to which approximations are required for each model or component processes omitted.

Approximations in climate models represent aspects of the models that require parameter choices and "tuning." As a simple example, imagine a single cumulus cloud and how it has to be represented in a global climate model. The cloud may encompass only a few hundred meters in the vertical and horizontal extent, which is much finer resolution than can be run on today's coupled atmosphere and ocean climate models. This then means that in order to incorporate such clouds into the climate model, some approximations have to be made regarding the statistical properties of such clouds within say an area 100 or 1000 times larger than the cloud itself. This is referred to as model parameterization, and the process of selecting the most appropriate parameters to best simulate observed conditions is called model tuning. Similar methods are also required in today's state-of-the-science weather forecasting models.

An important difference between weather forecasting models and climate models is that weather models are initialized with a specific set of observations representing today's weather to precisely predict the weather "x" days or hours into the future. The initial starting conditions of the climate models, however, are not nearly as important. Climate models are used to simulate many years of "weather" into the future with the intent of understanding the difference in the collection of weather events at some point in the future, compared to some other time in the past (often the climate of the last 30 years or so). This comparison enables scientists to study the output of climate model simulations to understand the effect of various modifications of those aspects of the climate system that might cause the climate to change. A key challenge in climate modeling is to isolate and identify cause and effect – which requires knowledge about the changes and variations of the external forcings controlling climate, and a comprehensive understanding of climate feedbacks (such as a change in the earth's reflectivity because of a change sea ice or cloud amount) and natural climate variability.

Model simulations of climate over specified periods can be verified and validated against the observational record. Models that prove to describe climate variability and change well can be used as a tool to increase our understanding of the climate system. Once evaluated and validated, climate models can then be used for predictive purposes. Given specific forcing scenarios, climate models can provide viable projections of future climate. In fact, climate models have become the primary means to predict climate, although prediction is ultimately likely to be achieved through a variety of means, including the observed rate of global climate change.

How do we know the global air temperature is increasing?

There has now been a comprehensive analysis of the changes of temperatures near the surface and throughout much of the atmosphere in the April 2006 Climate Change Science Program Synthesis and Assessment Report 1.1. This report addressed the nagging issue of differences in the rate of warming between measurements derived near the surface and those taken from the atmosphere. The surface air temperatures are derived from several different analyses teams using various combinations of ocean ships and buoys, land observations from weather reporting stations, and satellite data. Atmospheric data sets have been derived using satellites, weather balloons, and a combination of the two.

Considering all the latest satellite, balloon and surface records, the CCSP report concluded there is no significant discrepancy between the rates of global temperature change over the past several decades at the surface compared to changes higher in the atmosphere. The report does, however, acknowledge there are still uncertainties in the tropics, and this is primarily related to data from weather balloons. There is uncertainty as to whether scientists have been able to adequately adjust for known biases and errors in the data, especially in the tropics where many developing nations struggle to routinely launch weather balloons and process these measurements.

Globally, data indicate that rates of temperature change have been similar throughout the atmosphere since 1979 when satellite data were first available, and the rates of temperature change have been slightly greater in the atmosphere compared to the surface air temperature since 1958 (the time at which weather balloons had adequate spatial coverage for global calculations). The global surface temperature time series, shown in Figure 3, indicates warming on even longer time scales, with acceleration since 1976.

Instrumental temperature measurements are not our only evidence for increasing global temperatures. The observed increased melting of glaciers can be used to estimate the rate of temperature increase since the late 19^{th} Century. Estimates of the near-surface temperature based on glacial melting are very similar to estimates based on instrumental temperature data. There has been a 15-20 percent reduction in Arctic sea ice since the 1970s, a 10 percent decrease in snow cover since the 1970s, and shortened periods of lake and river ice cover (about 2 weeks shorter since the 19^{th} century). Also, ocean heat content has significantly increased over the past several decades (IPCC, 2001).

Why do we think humans are influencing the Earth's climate?

The scientific community has been actively working on detection and attribution of climate change as related to human activities since the 1980s. As described above, one set of tools often used to examine these issues are mathematical computer models of the climate. Outstanding issues in modeling include specifying forcing mechanisms (e.g., the causes of climate variability and change) within the climate system; properly dealing with complex feedback processes that affect carbon, energy, and water sources, sinks and transports; and improving simulations of regional weather, especially extreme events. Today's inadequate or incomplete measurements of the various forcing mechanisms, with the exception of well-mixed greenhouse gases, add uncertainty when trying to simulate past and present climate. Confidence in our ability to predict future climate depends on our ability to use climate models to attribute past and present climate change to specific causes.

Recent carbon dioxide emission trends are upward with increases between 0.5 and 1 percent per year over the past few decades. Concentrations of both reflective and nonreflective aerosols are also estimated to be increasing. Radiative forcings[4] from greenhouse gases dominate over the net cooling forcings from aerosols and the global temperature has exceeded the bounds of natural variability. This has been the case since about 1980. As an example of how models are used to detect human influence on the climate system Figure 4 shows that without including all the observed forcing mechanisms the models cannot replicate the observed global temperature changes. There are many other aspects of the climate system besides global surface temperatures that have been tested for human influences.

Today, there is convincing evidence from a variety of climate change detection and attribution studies pointing to human influences on climate. These include regional analyses of changes in temperature, the paleoclimatic[5] temperature record, three dimensional analysis of atmospheric temperature change, changes of free atmospheric temperature, changes in sea ice extent and other components of the cryosphere, changes in ocean heat content, and new studies on extreme weather and climate events. Thus, there is considerable confidence that the observed warming, especially the period since 1970s is mostly attributable to increases in greenhouse gases (IPCC, 2001; Karl et al., 2006; Stott et al., 2001; Stott et al., 2006; Tett et al., 2002; Hegerl et al., 2001; Gillet et al., 2002; Zhang et al., 2006; Allen, 2005; Zweirs and Zhang, 2003; Stone and Allen, 2005; Karoly and Wu, 2005; and many others).

Changes in Extremes in the United States

The U.S. Climate Change Science Program Synthesis and Assessment Report 3.3 will specifically address the issue of changes in extreme events, focusing on North America. This assessment will focus on a wide range of climate-related extreme events and promises to help clarify what we know and do not yet understand about these important events, as related to climate change. Here, three types of climate extremes are discussed as they are likely to be influenced by rising global temperatures. This includes changes the frequency and intensity of heavy and extreme precipitation events, droughts, and hurricanes.

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[4] Radiative forcing can be thought of as the change heat (expressed in Watts per square meter: Wm^{-2}) at the tropopause due to an internal change or a change in the external forcing of the climate system, such as, for example, a change in the concentration of carbon dioxide or the output of the Sun. The tropopause is the boundary between the troposphere and the stratosphere represented by a rather abrupt change from decreasing to increasing temperatures

[5] Climate during periods prior to the development of measuring instruments, including historic and geologic time, for which only proxy climate records are available. A proxy climate indicator is a local record that is interpreted, using physical and biophysical principles, to represent some combination of climate-related variations back in time. Climate-related data derived in this way are referred to as proxy data. Examples of proxies are: tree ring records, characteristics of corals, and various data derived from ice cores.

Increasing air temperature leads to increased water vapor in the atmosphere. By raising the air temperature, the capacity of the atmosphere to hold more water vapor is increased, which defines the upper bounds of the amount of precipitation that can occur during short term (~daily or less) extreme precipitation events. Surface moisture, if available (as it always is over the oceans), effectively acts as the "air conditioner" of the surface – as heat used for evaporation moistens the air rather than warming it. Therefore, another consequence of global heating of the lower troposphere is accelerated land-surface drying and more atmospheric water vapor (the dominant greenhouse gas). Satellite measurements now confirm a significant increase in atmospheric water vapor (Trenberth et al., 2005; Dai et al.,2005), consistent with theoretical expectations given the rate of observed atmospheric warming during the past several decades. Accelerated drying, without an increase in precipitation, increases the incidence and severity of droughts (Dai et al., 2004), whereas additional atmospheric water vapor increases the risk of heavy precipitation events (Trenberth et al., 2003). Increases in global temperature also increase sea surface temperatures, one of several important factors affecting the hurricane intensity.

NOAA's National Climatic Data Center calculates a Climate Extremes Index (CEI) over the United States that includes extremes related to all of these indicators including temperature, precipitation, drought and hurricanes. Although no index can claim to adequately capture all of the important changes in extremes, the changes and variations of the CEI as reflected in Figure 5 is illustrative of the varying decadal variability of climate extremes. Currently, the CEI is at record levels during the past decade or so, but not much higher than in previous decades, so there is no clear indication of a general increase in the aggregate set of extremes included in the CEI when viewed across much of the 20th Century.

Changes in Heavy and Extreme Precipitation

Basic theory, climate model simulations, and empirical evidence (Figure 6) confirm that warmer climates, owing to increased water vapor, lead to more intense precipitation events even when the total precipitation remains constant, and with prospects for even stronger events when precipitation amounts increase. Figure 7 depicts the aggregate land-surface world-wide changes in heavy precipitation events over the last half of the 20th century with an associated geographic depiction of where changes in heavy precipitation have occurred, with most areas showing increases. World-wide, an increase of a few percent in heavy precipitation events is evident since the middle of the 20th century, particularly in the middle and high latitudes. By the end of the 21st Century a conservative estimate of the projected increase in the amount of precipitation that would occur in one day (a one-in-twenty-year heaviest daily precipitation event) is between 10-20 percent (Zweirs and Zhang, 2005). This assumes carbon dioxide does not exceed 550 ppmv[6].

[6] Such a scenario is built on the storyline of relatively low population growth and with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies.

The practical implications of addressing these changes are seen in NOAA's recent update of the Ohio River Basin's 100-year 24-hour precipitation return period. These data are used to help set engineering design standard related to excessive rainfall. Over the past several decades increases in the amount of precipitation occurring in the heaviest daily precipitation events has been observed in many areas of central and eastern United States over the past several decades (Karl and Knight, 1998; Groisman et al., 2004; Groisman et al., 2005).

In many geographic regions increases in extreme precipitation is occurring, even when changes in total precipitation are relatively constant (Groisman et al., 2003 and 2005; Alpert, 2005).

Changes in Drought Severity and Frequency

Drought is a recurring feature of the climate system. In other words, we have had major droughts in the past, and expect to have major droughts in the future. At any given time, at least part of the U.S. is in drought, with percentages ranging from 5-80 percent of the total land area. U.S. droughts show pronounced multi-year to multi-decadal variability, but no convincing evidence for systematic long-term trends toward more or fewer events. Drought calculations have been made showing that over the U.S. the increase in temperatures that may have led to increased evaporation has been compensated by a general increase in precipitation over the past few decades (Dai et al., 2004) as there has been no general trend in drought intensity across the United States (Figure 8). Over the U.S. there are no clear patterns of precipitation increase that has emerged from climate model simulations as global temperatures increase, so the increase in precipitation over the past few decades may not persist and could reverse. Such a reversal, added to the continuing increase in temperatures, such as the recently observed record high January though June of 2006 (NOAA Press Release, July, 2006), could lead to greater drought severity and frequency, especially during periods of dry weather due to increases in evaporation.

For the continental U.S., the most extensive U.S. drought in the modern observational record occurred from 1933 to 1938. In July 1934, 80 percent of the U.S. was gripped by moderate or greater drought (Figure 8), and 63 percent was experiencing severe to extreme drought. During 1953-1957, severe drought covered up to 50 percent of the country. Paleoclimatic data (e.g. tree ring measurements) have been used to reconstruct drought patterns for the period prior to the modern instrumental record (Cook et al., 1999 and 2004). These reconstructions show that during most of the past two millennia the climate of the western U.S. has been more arid than at present. The recent intense Western drought from 1999 to 2004 that strongly affected the Colorado River basin was exceeded in severity as recently as the 19^{th} century. Within the past millennium there have been severe droughts in both the western U.S. and Midwest that have lasted for multiple decades.

Long-term warming trends have also led to changes in the timing of snow melt and stream flows, especially in the West. This is resulting in earlier peak stream flows and diminished summer-time flows.

Drought is a recurring feature of the climate in the US and as temperatures increase this will lead to increased drying during periods of dry weather leading to more intense droughts.

Changes in Hurricane Intensity and Frequency

Tropical storms and particularly hurricanes, are an important issue of concern for the United States. The record-breaking hurricane season of 2005, and especially the havoc created by Katrina, raised public awareness of the dangers of hurricanes to new heights. Hurricanes respond to a number of environmental factors including ocean temperatures, atmospheric stability, El Niño, and other factors. One important question is whether hurricane activity has changed over the last 100 years. Since 1995, Atlantic hurricane activity has significantly increased, with more hurricanes, and more intense hurricanes, compared to the two previous decades and this is also reflected in those hurricanes striking the U.S. (Figure 9). However, earlier periods, such as the 1945 to 1970 period were nearly as active.

An important consideration in hurricane intensity is a trend toward warmer sea surface temperatures, particularly in the tropical Atlantic and Gulf of Mexico, indicating climate change may play some role in the increased hurricane intensity (Emanuel, 2005; Webster et al., 2005). Another factor is a slow cycle of natural fluctuations in atmospheric conditions and ocean temperatures in the North Atlantic referred to as the Atlantic Multi-decadal Oscillation (AMO). This AMO is currently in a warm ocean temperature phase.

What does the future hold for hurricane activity? In the near term, it is expected that favorable conditions for Atlantic hurricanes will persist for the next decade or so based on previous active periods. For the longer term, climate models project an increase in the intensity of strong hurricanes late in the 21st Century Knutson, (2006). Specifically, this translates to increases in wind speed and about a ½ category increase in intensity on the commonly used Saffir-Simpson Hurricane Intensity Scale as tropical sea surface temperatures increase by nearly 2°C. Given those conditions (stronger hurricanes and warmer tropical sea surface temperatures) climate models also predict an increase in storm rainfall rates of about 20 percent (Knutson 2006). However, it is unclear if the total number of hurricanes will change in future years (IPCC, 2001).

New analyses of precipitation rates for different strengths of landfalling Atlantic tropical cyclones (both hurricanes and tropical storms) over the southeastern United States have recently been completed. These analyses (Karl et al., 2004; Groisman et al, 2006) show that daily precipitation amounts increase with tropical cyclone strength, while hourly precipitation does not. This means that the more intense hurricanes have longer periods with heavy rainfall. The implications are relevant for local planning, if indeed tropical cyclone strength increases in the future.

Overall, the issue of hurricanes and climate change is an ongoing debate. The scientific community has varying viewpoints on the magnitude of influence of global climate change on hurricanes and how long the current active period will last. NOAA recognizes the debate and continues to study hurricane development, intensity, activity, and modeling.

Conclusion

The state of the science continues to indicate that modern climate change is affected by human influences, primarily human-induced changes in atmospheric composition. These perturbations result mainly from emissions associated with energy use, but on local and regional scales, urbanization and land use changes are also important contributors to climate change. While there is still considerable uncertainty about the rates of change that can be expected, it is clear these changes will be increasingly manifested in important and tangible ways, such as changes in extremes of temperature and precipitation, decreases in seasonal and perennial snow and ice extent, sea level rise, and now there is accumulating evidence to suggest that there will be increases in hurricane intensity and related heavy and extreme precipitation. Furthermore, while there has been progress in monitoring and understanding the causes of climate change, there remain many scientific, technical, and institutional challenges to precisely planning for, adapting to, and mitigating the effects of climate change. The U.S. Climate Change Science Program is addressing the scientific dimensions of these challenges by facilitating the creation and application of knowledge of the Earth's global environment through research, observations, decision support, and communication. The program's vision is to improve the nation's ability to manage the risks and opportunities of change in the climate and related environmental systems. Within the next two years the program will produce a series of synthesis and assessment reports that describe the scientific state-of-the-art on a range of key issues, thereby providing further important contributions to the nation's discussions of climate change. As mentioned above, the first in the series (Climate Change Science Synthesis and Assessment Product 1.1) was released earlier this year on the topic of temperature trends, and has already made a valuable contribution to the national dialogue.

Thank you again, Mr. Chairman for allowing me the opportunity to help inform the Committee about climate change.

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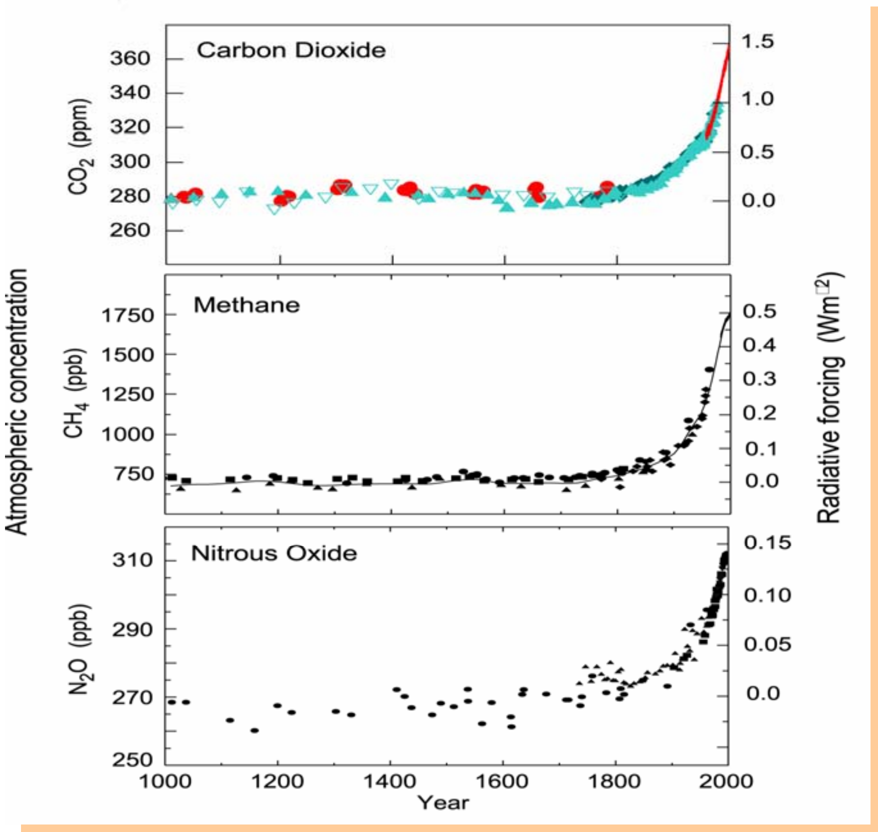

Figure 1: Changes in atmospheric concentration of carbon dioxide, methane, and nitrous oxide since 1000 A.D. (from IPCC, 2001).

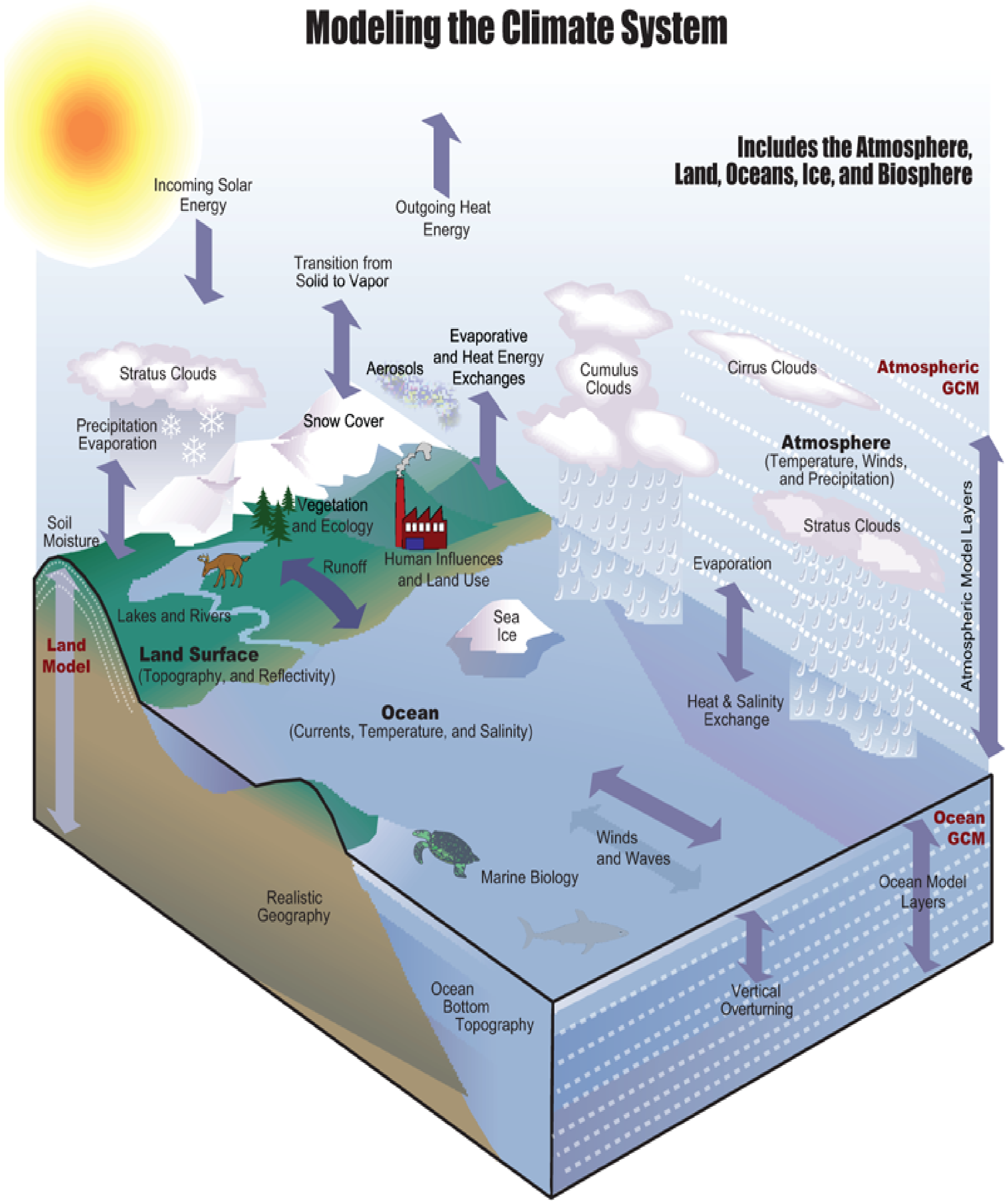

Figure 2. Components of the climate system and the interactions among them, including the human component. All these components have to be modeled as a coupled system that includes the oceans, atmosphere, land, cryosphere, and biosphere.

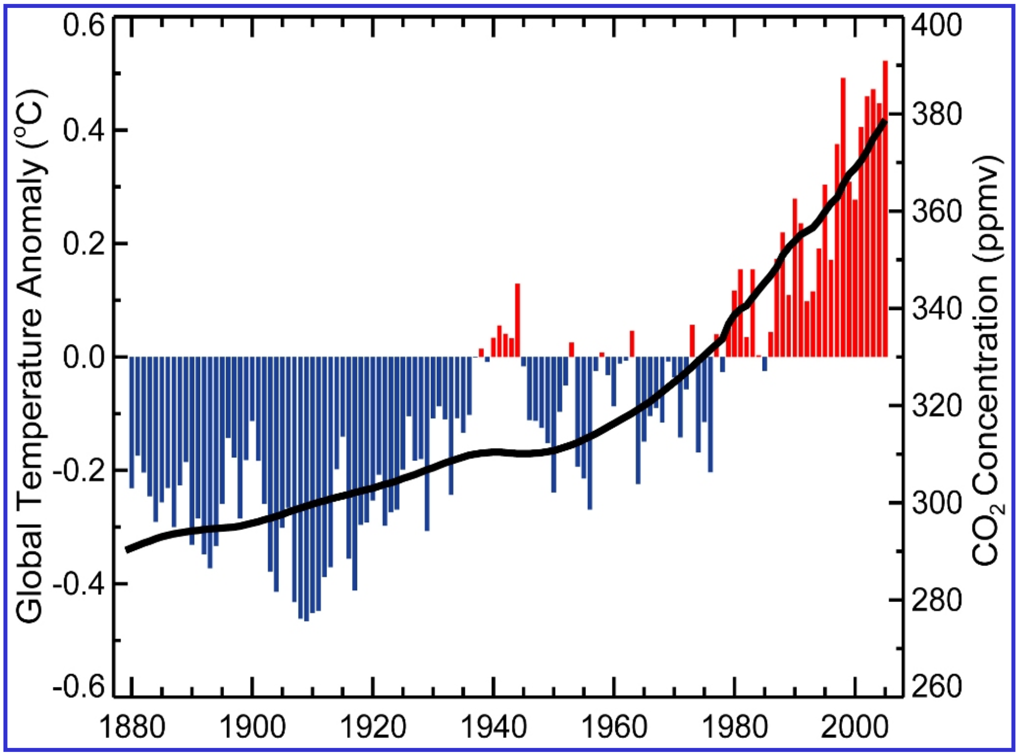

Figure 3: Globally averaged surface air temperature and carbon dioxide concentration (parts per million by volume) since 1880 (Updated from Karl and Trenberth, 2003).

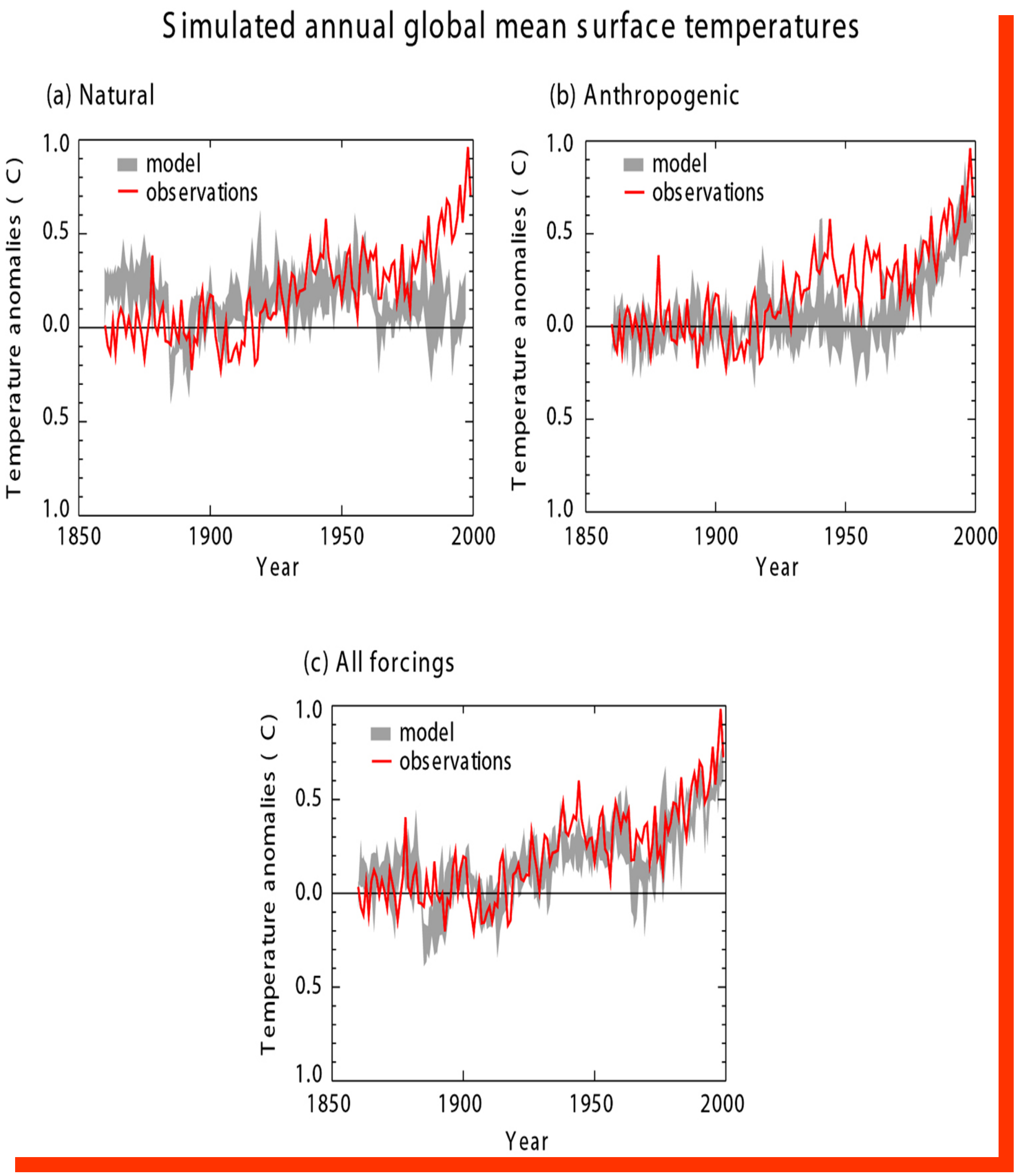

Figure 4: Climate model simulations of the global air temperature for the period 1860-2000. Figure 4a includes only natural forcing mechanisms such as volcanic eruptions and solar variability; 4b includes only anthropogenic greenhouse gas increases; and 4c includes both natural and anthropogenic forcing mechanisms (from IPCC 2001).

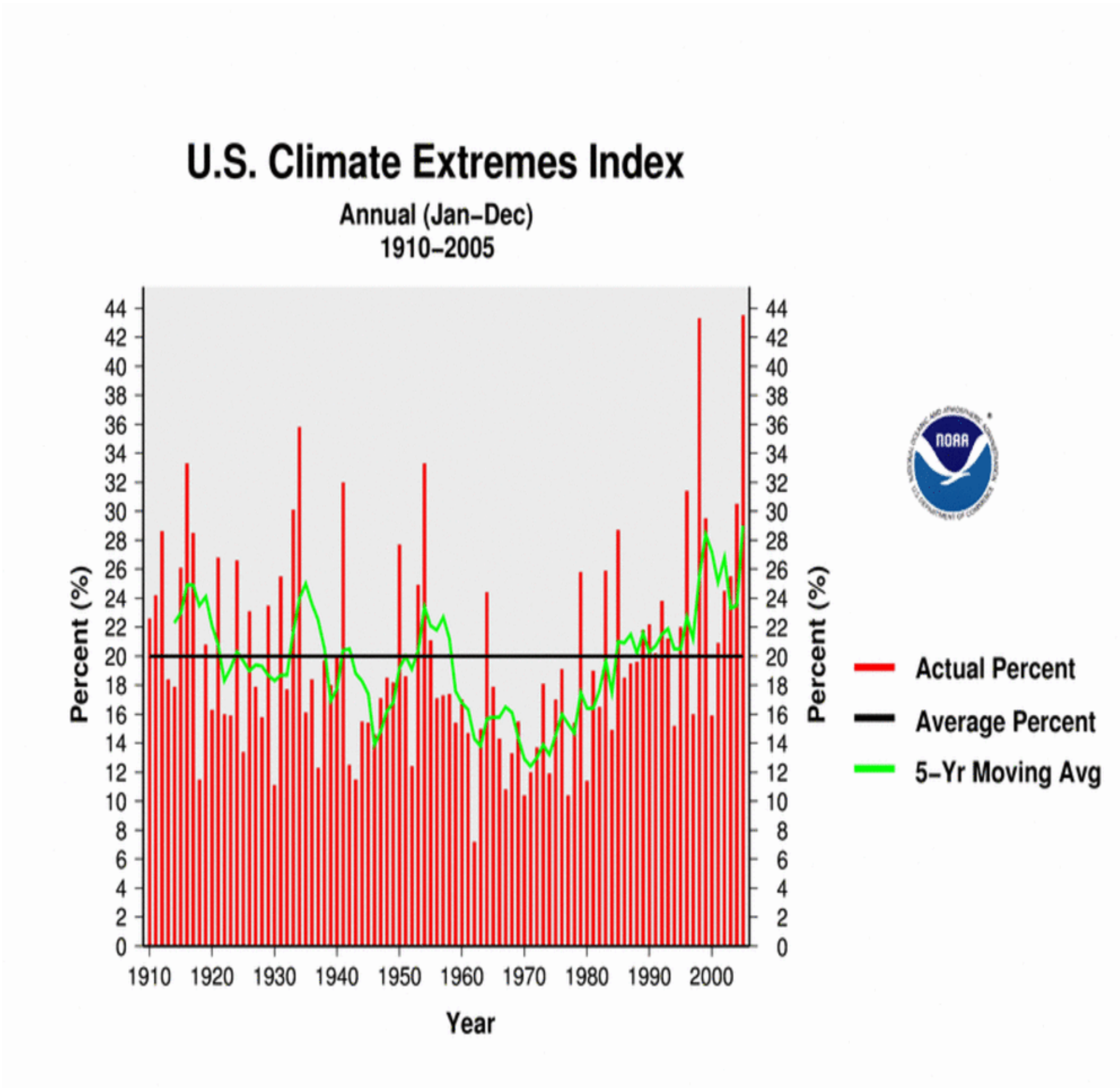

Figure 5: The U.S. Climate Extremes Index (CEI) is the average of the percent of U.S. land area experiencing extremes in temperatures, drought, precipitation, and tropical storms. More detailed information on the CEI is available at http://www.ncdc.noaa.gov/oa/climate/research/cei/cei.html.

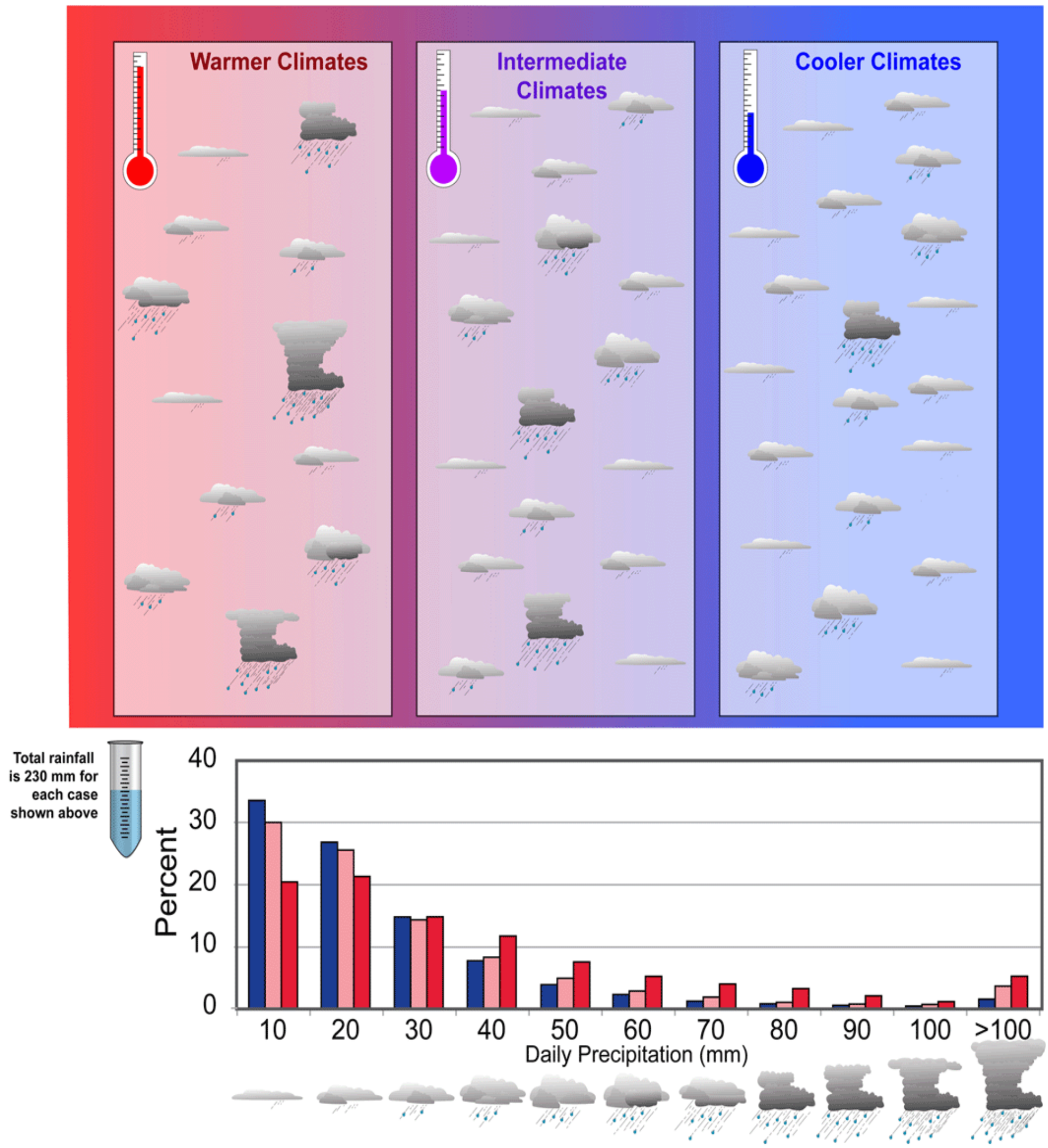

Figure 6: The diagram shows that warmer climates (red) have a higher percentage of total rainfall coming from heavy and very heavy events. The data are based on a worldwide distribution of observing stations, but each have the same seasonal mean precipitation amount of 230 (±5) mm. For cool climates (blue), there are more daily precipitation events than in warmer climates (Adapted from Karl and Trenberth, 2002). The various cloud and rain symbols reflect the various daily precipitation rates and have been categorized in the top panel of this figure to reflect the approximate proportion of the various precipitation rates for cool, moderate, and warm climates across the globe.

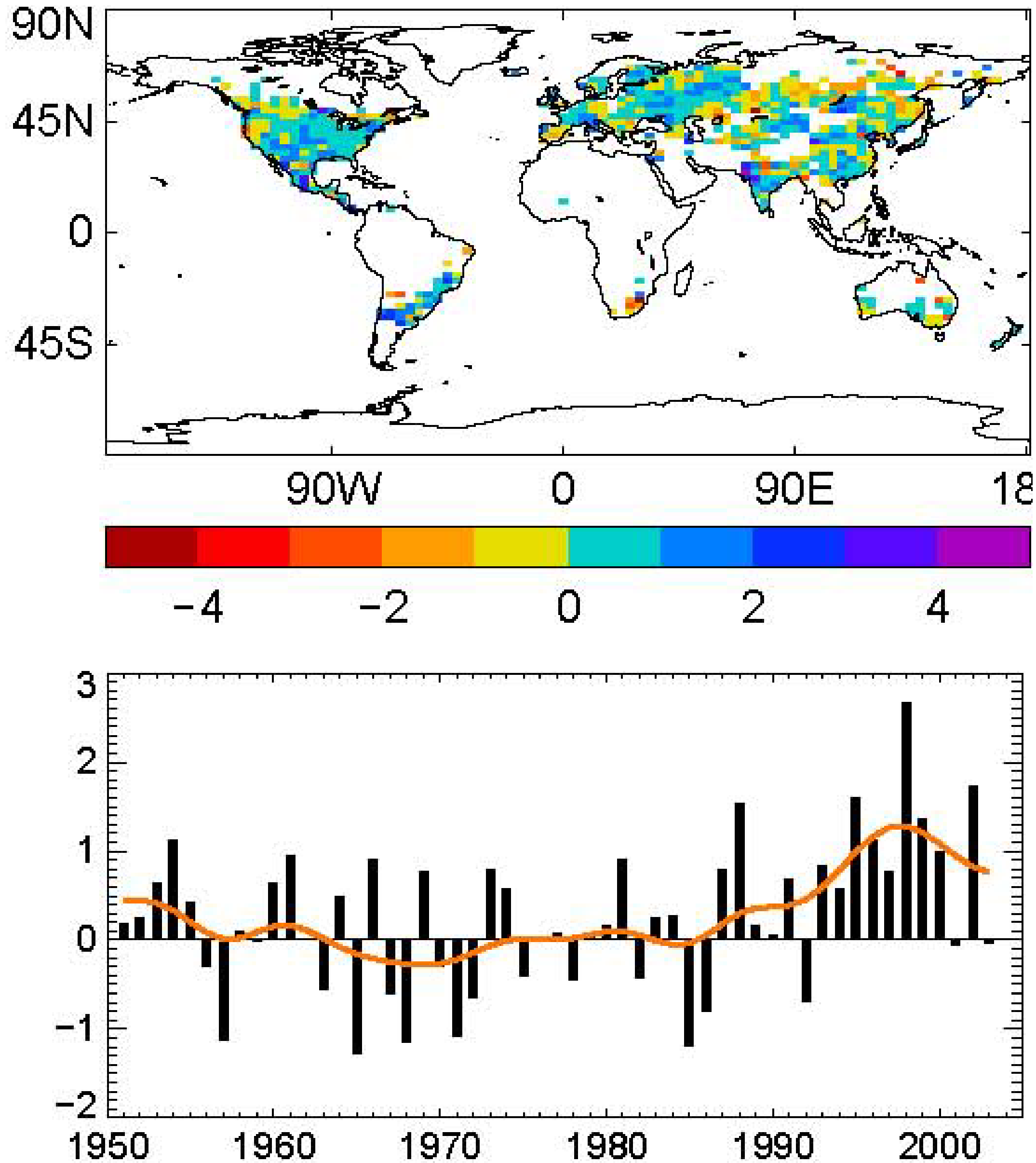

Figure 7: Changes in the contribution of heavy precipitation events to the annual total amount. The annual values are smoothed by the orange line to better represent decadal variability and change. Globally there has been a change of nearly two percent since the mid-20th century (from Alexander et al., 2006: Global observed changes in daily climate extremes of temperature and precipitation. *J. Geophys. Res*., D05109, doi:10.1029/2005JD006290).

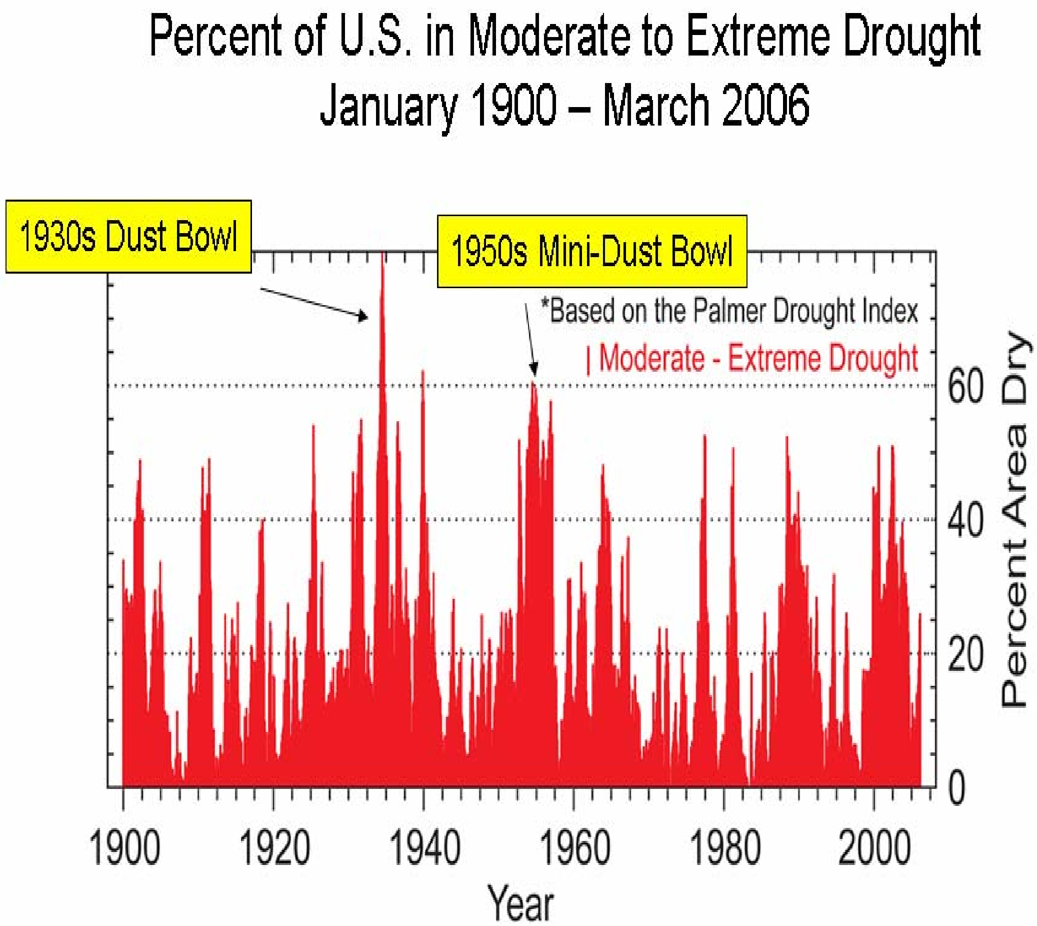

Figure 8: The percentage of the contiguous U.S. land area in moderate to severe drought (NOAA, National Climatic Data Center).

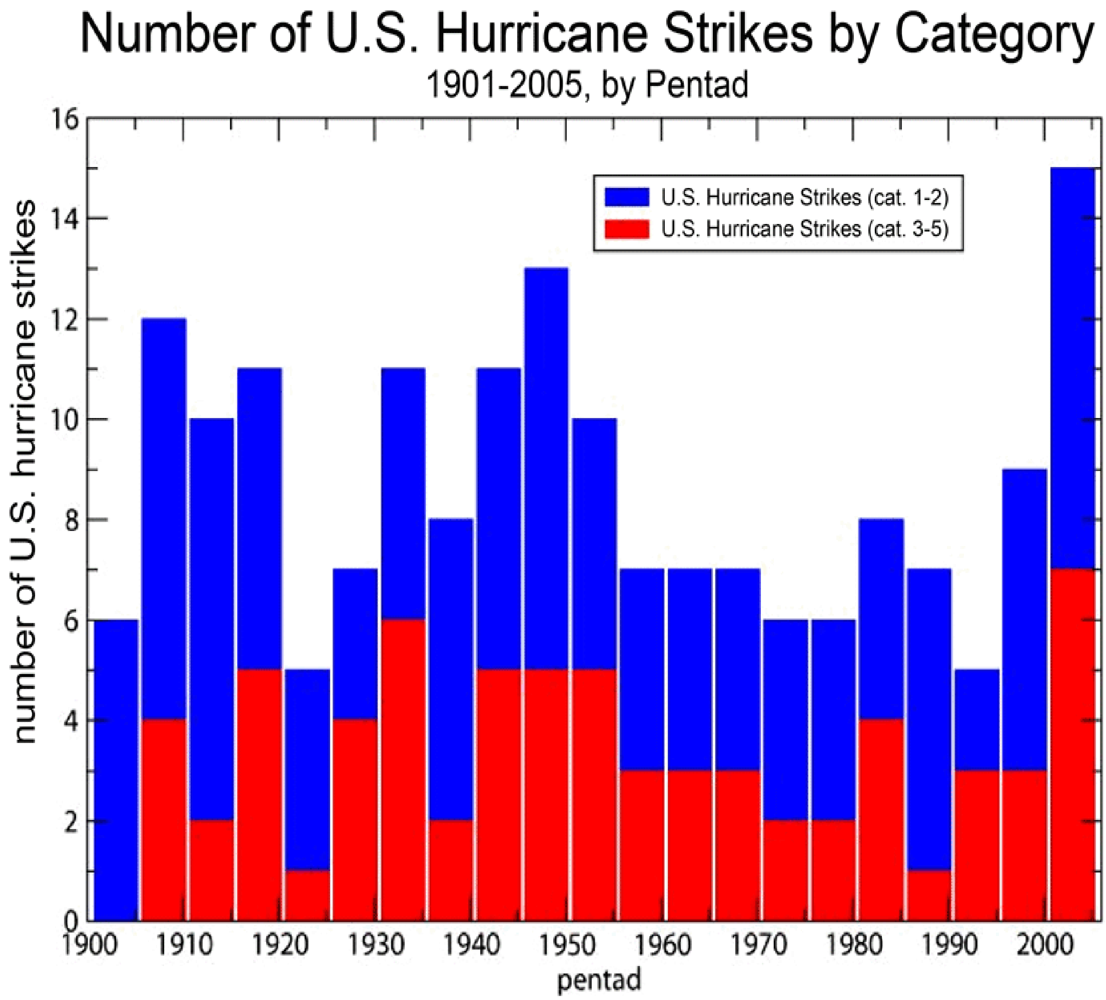

Figure 9: The number of hurricanes striking the U.S. summed by five year periods (e.g. 1901-1905, 1906-1910, etc.). The red bar is the number of major hurricanes (category 3-5) and blue bar is the number of weaker category 1 and 2 hurricanes per five year period (pentad). (NOAA, National Climatic Data Center)